Image sensing device and method

Technical Field

This invention relates to an image sensing device for
5 digital image capture apparatus such as digital still
cameras and analog and digital video cameras, scanners
such as film or flat bed scanners, and other imaging
systems and devices.

10 ## Background of the Invention

Unlike traditional cameras that use film to capture and
store an image, digital cameras and other digital image
capture devices as well as analog video cameras use a
solid-state device, which is referred to herein as an
15 image-sensing device to create an electronic
representation of the image being captured. One type of
image-sensing device which is in common usage is a mosaic
type device in which an imaging photosensor array such as
a Charge Coupled Device (CCD), a Charge Injection device
20 (CID) or a CMOS detector array is tiled with color filters
in a Bayer pattern, in stripes or in some other regular
arrangement. One example of such a prior art device is a
Sony ICX205AK Progressive Scan CCD Image Sensor for Color
Cameras. Image-sensing devices can contain millions of
25 sampling sites, each having a photosensitive device or
'sensor' and the photosensors being divided into a
plurality of color channels. Each sensor records the
intensity of the light that falls on it by converting
photons into an electrical charge and accumulating the
30 electrical charge over a fixed period of time. For each
sensor, the collected charges are then processed into a
signal which is subsequently digitized and the digital
products saved in one of the many known digital image
formats from which the image may be displayed, printed or
35 further processed.

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The photosensor's sensitivity to light varies as a function of wavelength. This sensitivity is usually adjusted to correspond to a particular color of light by means of a filter which selectively attenuates the light
5 as a function of frequency.

One commonly used system utilizes filters representative of three additive primary colors of red, green, and blue (RGB), however other color systems are also known,
10 including for example a system which utilizes filters of cyan, magenta, yellow and green. The selection of the colors comprising a set of primary colors is to some extent arbitrary and in theory many colors could be used. In a system whereby the colors are too broad, for example,
15 cyan, magenta and yellow, the final computed RGB values generally suffer from an excess of noise. Conversely, if the colors are too narrow, the camera will have gaps in its sensitivity. For example, if red and green are very narrow, a yellow colored object which falls right between
20 the passbands of the two filters may not be visible to the camera at all.

Typical wavelength values of primary colors in an RGB system are 640nm (red), 537nm (green), and 464nm (blue).
25
A well known technique used in many digital cameras for recording color images involves placing one color filter over each individual photosensor so that each photosensor can capture only one of the primary colors of the
30 particular color system in use. For instance for an RGB system, repeating patterns of photosensors may be arranged such that each one of these photosensors has either a green, red, or blue filter placed to filter the light falling onto it.
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Some manufacturers of digital cameras have used even more than three different filter colors. For instance, Hewlett Packard has previously developed a camera that used four color channels with filters of cyan, magenta, yellow and
5 green. Whilst it is common practice to convert from one set of colors to another (eg. from the sensor color system to a target color system) using a linear transformation, the conversion has the disadvantage of amplifying the signal noise. Furthermore, the amplification of noise
10 increases when the difference between the target set of colors and the sensor set of colors increases.

The majority of manufactures of digital cameras therefore use image sensor devices employing a three-color system in
15 which each filter/photosensor combination has a profile that approximates the corresponding desired output target color. However this solution is problematic in that the target colors each have a narrow spectral bandwidth and as a result, the sensors do not record very much light. In
20 some imaging applications a greater output is achieved by adopting filters associated with the photosensors which have spectral bandwidths that are more broadly tuned than would be ideal for optimal color rendition. Whilst this approach has the advantage of improving color sensitivity
25 it also has the drawback of reducing the overall color quality. Furthermore, heightened sensitivity is only useful in shadow regions and generally causes saturation in highlighted areas of the resultant image.

30 Another type of image sensing device which is sometimes seen in more expensive imaging systems employs a beam splitter to split the light delivered from a lens system into several paths each of which include a color filter and an image photosensor array. This approach avoids
35 having to create a mosaic of filters in front of the photosensors, but introduces losses associated with the

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beam splitter, is bulkier and requires one photosensor array for each of the beams emerging from the beam splitter.

5   Prior art systems, where each color channel of an image sensing device contains sensors sensitive to a single spectral bandwidth, therefore suffer from either low saturation levels causing loss of detail in highlight areas and/or restricted sensitivity causing loss of detail

10 in shadow areas and possibly further loss of detail where image colors fall between the spectral bandwidths of the respective color channels.

Summary of the Present Invention

15 Accordingly an image sensing device is provided comprising a plurality of photosensors arranged in at least one array, such that each of the photosensors converts incident light into an output signal, the photosensors and their respective output signals being

20 divided into a plurality of color channels. A filter is associated with each of the photosensors, the filters selecting light within predetermined spectral bands for conversion by the photosensors into the output signals. One of the color channels is divided into at least two

25 sub-channels and the filters associated with the photosensors of the at least two color sub-channels have overlapping spectral bands wherein one of the overlapping spectral bands is narrower in bandwidth than another of the overlapping spectral bands.

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An image sensing device and a method of capturing an image will now be described by way of example, with reference to the accompanying drawings.

Brief Description of the Drawings

Fig. 1 is a schematic illustration of an image-sensing device with one portion shown in detail and in which a matrix of photosensors are provided arranged into four
5 color channels or sub-channels;

Fig. 2 is a schematic illustration of a portion of the image-processing region of a digital image capture device into which the image sensing device of Fig. 1 is
10 incorporated;

Fig. 3 is a schematic illustration of an alternative image-sensing device in which four arrays of photosensors are provided, each array associated with a respective
15 color channel or sub-channel and light is distributed to each of the arrays by way of a beam splitter;

Fig. 4 is a schematic illustration of a further alternative image-sensing device in which three arrays of
20 photosensors are provided and light is distributed to each of the arrays by way of a beam splitter whereby two of the arrays are associated with a respective color channel and the third array is associated with two color sub-channels.

25 Fig. 5 graphically illustrates a response function from a first and second color sensor of a single color channel (such as the green color channel of the embodiment of Fig. 1) in an image sensing device; and

30 Fig. 6 is a flow chart of a method of capturing an image.

Detailed Description of Embodiments of the Present Invention

Fig. 1 schematically illustrates a portion of an image-
35 sensing device 100 showing in detail a subset 102 of the photosensors of the device and in particular a grouping

104 of four photosensors 106, 108, 110, 112 of the device.
Each grouping 104 has a first color channel comprising a
'red color photosensor' 106, a second color channel
comprising a 'blue color photosensor' 108, and a third
5   color channel comprising a first green color sub-channel
having a first 'green color photosensor' 110 and a second
green color sub-channel having a second 'green color
photosensor' 112. Each of the four color photosensors,
106, 108, 110 & 112 comprises a photodiode 114, 116, 118 &
10 120 and filter 122, 124, 126 & 128 in combination to
filter out all but the wanted wavelengths of the incident
light and to convert the wanted wavelengths into output
signals of the respective color channel or sub-channel.
In the case of the green color channel, the first green
15 filter/photosensor combination 110 has a filter 126 which
is tuned to accept a broader band of wavelengths than the
second green filter/photosensor combination 112 and
therefore the first filter/photosensor combination has a
higher sensitivity and is able to register lower levels of
20 light than the second filter/ photosensor combination. In
contrast the second green filter/photosensor combination
112, because it is tuned to a narrower band of wavelengths
than the first green filter/photosensor combination 110,
has a lower sensitivity than the first filter/photosensor
25 combination 126, 110, and is therefore less easily
saturated.

Image-sensing devices may, be integrated using
architectures such as CCD, CID or CMOS architecture. The
30 image-sensing device 100 may for example employ a sensor
chip such as a Sony^{tm} ICX205AL Progressive Scan CCD Image
Sensor for B/W Cameras, to which a mosaic of primary color
filters has been fitted. Alternatively the design of a
device such as a Sony^{tm} ICX205AK Progressive Scan CCD Image
35 Sensor for Color Cameras may be modified to replace half

of the green filters in the in-built mosaic of filters
with filters having a narrower acceptance bandwidth.

The image sensing device may be incorporated in an image
5 capture apparatus such as an analog or digital video
camera, a digital still camera, a scanner such as film or
flat bed scanner, or other imaging systems and devices.

The filters 122, 124, 126, 128 may for example comprise:-
10   1) Kodak^{tm} Wratten^{tm} #58 (green tricolor) for the
        first green filter 126
     2) Kodak^{tm} Wratten^{tm} #99 (green) for the second green
        filter 128
     3) Kodak^{tm} Wratten^{tm} #25 (red tricolor) for the red
15   filter 122
     4) Kodak^{tm} Wratten^{tm} #47 (blue tricolor) for the blue
        filters 124

Fig. 2 is a schematic illustration of a portion of the
20 image-processing region of a digital image capture device
into which the image-sensing device of Fig. 1 is
incorporated. The image-sensing device in this example is
a CCD 200. In accordance with CCD architecture a shift
control circuit 202 controls the transport of an output
25 signal from each photosensor location 204 to the next
across the photosensor array 206. The output signals 208
on the last row 210 of the photosensor array 206 are then
transferred to the readout register 212. Once the signals
in the last column 210 of photosensor locations 204 has
30 been shifted to the readout register 212, the signals in
the readout register are sequentially shifted into an
analog to digital (A/D) converter 214 where they are
digitized before being stored in digital memory 216 of a
microprocessor 218. Once all of the pixels in the readout
35 register 212 have been digitized and stored, the signals
in the photosensor array 206 are again shifted by one

photosensor location toward the readout register 212 such that the new signals in the last column 210 of photosensor locations 204 after the previous shift operation enter the readout register 212. This process continues until all of
5 the signals in the photosensor array 206 have been read out. The captured and stored image is then available for further processing or for reconstruction for display on a display monitor or for printing.

10 An alternative embodiment of an image sensing device is schematically illustrated in Fig. 3. In this embodiment, only a portion of which is shown, light typically enters the system 300 through a lens system 302 and is passed through a beam splitter 304 (eg. a series of prisms) which
15 splits the light entering the imaging system into three color channels red, blue and green, where the green color channel has first and second sub-channels. Four image sensing devices 306, 312, 318 and 324 are provided, each comprising an array of photosensors, 310, 316, 322 and
20 328, and a filter 308, 314, 320 and 326 where each filter covers the entire area of the respective photosensor array. Each array of photosensors 310, 316, 322 and 328 may be implemented using a device such as the Sony^{tm} ICX205AL Progressive Scan CCD Image Sensor for B/W Cameras
25 or any similar device that does not include a mosaic of filters.

Photosensors 310 and 316 of sensors 306 and 312 convert light in spectral bands that approximate the primary
30 colors red and blue respectively. Photosensor 318 of image sensor 306 converts light in a first broad spectral band which approximates the primary color green whereas photosensor 328 of image sensor 324 converts light in a second narrower spectral band which also approximates the
35 primary color green in a similar manner to the green sub-channels of the earlier embodiment. The photosensor

arrays are then each unloaded in a similar fashion to that
of the previous embodiment and the image components are
then combined in an image processor (not shown).

5 A further alternative embodiment of an image sensing
device is schematically illustrated in Fig. 4, in which
only a portion of the device is shown.

In this embodiment, similar to the embodiment illustrated
10 in Fig. 3, light enters the system 400 through a lens
system 402 and is passed through a beam splitter 404 which
splits the light entering the system into three color
channels red, blue and green. In this embodiment, three
image sensing devices 406, 412, and 418 are provided.
15 Image sensing devices 406 and 412 each comprise an array
of photosensors 410 and 416 and respective filters 408 and
414 where each filter covers the entire area of the
respective photosensor array. Photosensors 410 and 416 of
sensors 406 and 412 convert light in spectral bands that
20 approximate the primary colors red and blue respectively.

Image sensing device 418 on the other hand comprises an
array of photosensors 422 of which only a grouping of four
photosensors 424 is shown in detail. Each grouping has a
25 pair of first green color sensors diagonally spaced from
one another, each having a photodiode 426 and a filter 428
and a pair of second green color sensors each having a
photodiode 430 and a filter 432. The filter 428 of the
first green filter/photosensor combination is tuned to
30 accept a broader rang of wavelengths than the second green
filter/photosensor combination.

The image-sensing device may comprise three or more color
channels. In an alternative arrangement to those
35 described above four color channels are provided where

each of the channels is indicative of the one of the colors cyan, magenta, yellow and green respectively.

In a variation of the three color arrangements described above, the green color channel may comprise three or more sub-channels such that a filter of the first sub-channel is broadly tuned in spectrum, a filter of the second sub-channel is narrowly tuned in spectrum, and the filters of the remaining sub-channel(s) are tuned to bands between those of the first and second sensors.

In particular applications it may for example be advantageous to provide two or more sensors for the red channel or the blue channel rather than the green channel.

Narrow band filters that may possible be used in a red sub-channel include Kodak^{tm} Wratten^{tm} 29 or 92 and narrow band filters that may possible be used in a blue sub-channel include Kodak^{tm} Wratten^{tm} 47B or 98.

In a still further example, more than one of the color channels and possibly all of the color channels may each comprise a plurality of sub-channels such that a filter of the first sub-channel for each respective color channel is broadly tuned in spectrum, the filter of the second sub-channel for each respective color channel is narrowly tuned in spectrum and the filters of any remaining sub-channels are tuned to bands between those of the first and second sub-channels of the respective color channel.

It should be appreciated that the invention is not limited to any particular combination of sensors and color channels and that the examples provided above are provided for illustrative purposes only.

The graph illustrated in Fig. 5 shows output
characteristics for two photosensors 502, 504 having
filters with different spectral bandwidths (eg. Kodak^{tm}
Wratten^{tm} #58 (green tricolor) and Kodak^{tm} Wratten^{tm} #99
5 (green)) associated with two sub-channels of a single
color channel of a photosensor array. The filter of the
first photosensor 502, is tuned to a broad spectral
bandwidth, whilst the filter of the second photosensor
504, is tuned to a narrow spectral bandwidth.
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For low levels, or intensities of incident light on each
photosensor 502, 504, the output of the sensor will not
rise above an inherent noise floor and any useful signal
is accordingly masked. Incident light levels falling at
15 or below the noise floor are accordingly treated as black
levels. On the other hand when high incident light levels
fall on a sensor, the sensor is caused to saturate.
Levels between these two extremes can be recorded by the
photosensor as varying shades or tones between the black
20 and saturation levels.

Referring again to the graph of Fig. 5, the combined
effect of the two photosensors 502 and 504 is to provide
five different output areas depending on the intensity of
25 the incident light that registers on each of the sensors.
Area A represents darkness, where the signal generated by
each of the sensors is unregistrable over the noise level.
Area B represents areas of shadow detail, or regions of
relatively low light intensity where only the photosensor
30 502 with a broad spectral-band filter registers a signal
raising above the noise floor. In Area B, the photosensor
502 is able to register light because broad spectral
bandwidth of the filter associated with the photosensor
rejects fewer photons than that of the narrow-band
35 photosensor 504. In contrast, the signal generated by the
narrow spectral-band photosensor 504 still remains

unregistrable over the noise level because the narrower spectral-bandwidth of the filter associated with the photosensor rejects a larger proportion of the incident photons. Area C represents mid-tones, where the intensity

5 of light incident on each of the photosensors 502 and 504 is sufficient for them to generate a signal that is above the noise floor. The fourth Area, D represents areas of highlight detail, or regions of relatively high light intensity where only the photosensor 504 with a narrow

10 spectral-band filter registers a signal below the saturation level. In Area D, the photosensor 504 is able to register a non-saturated signal because the narrow spectral-bandwidth of the filter associated with the photosensor rejects a larger proportion of incident

15 photons than the broad-band photosensor 502 and is therefore less easily driven into saturation. In contrast, at this intensity of incident light, the broad spectral-band filter of photosensor 502 is passing more photons than are required to drive the output of the

20 photosensor into saturation. Finally, area E represents full highlight, where both of the photosensors have been driven into saturation. By suitably scaling and combining the output signals of the two photosensors 502 and 504 it is possible to generate a range of recorded light

25 intensities within a given color channel which greatly exceed those that can be captured with a single photosensor. Employing more than two photosensors per color channel can further extend the range.

30 In comparison with prior art systems where each color channel of an image sensing device contains sensors sensitive to a single spectral band, this image sensing device has the advantage of improved dynamic range or exposure latitude and offers the possibility of improved

35 sensitivity providing greater detail in shadow areas and/or higher saturation levels giving improved detail in

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highlight areas. As illustrated in Fig. 5, the combination of dual sensors for a single color provide a useful output over a greater range of input intensities than will be the case for a single sensor.

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A method of capturing an electronic representation of an image will now be described. In a first step of the method, the image is projected onto a sensor device comprising a plurality of photosensors. The wavelengths

10 of light incident on each photosensor are restricted to a spectral band defining a color associated with the color channel of the respective photosensor. The output of each photosensor is therefore a measurement of the intensity of light incident on the respective photosensor. The outputs

15 of the photosensors are then combined to generate an electronic representation of the image. One color channel is divided into at least two sub-channels having overlapping spectral bands wherein one of the overlapping spectral bands is narrower in bandwidth than another of

20 the overlapping spectral bands.

Referring to Fig. 6 a flow chart 600 is illustrated showing the steps of the image capturing method. The first step 502 in any imaging process is to project the

25 image onto the sensor device. This is typically performed by using a lens system to focus light from a scene (or in the case of a scanning system from a document or item to be scanned) onto the image sensor device. Depending upon the type of imaging system in use, the projected image is

30 distributed 604 to sensors associated with different color channels, either by mixing the individual photosensors in a single photosensor array, or by splitting the projected image into a number of beams (using a beam splitter) and using a separate array to detect each color channel. In

35 either case a filter is used in the light path to each photosensor to restrict 606 the wavelengths of light

incident on each photosensor to only those wavelengths associated with the color channel of the photosensor. In the case of the light splitter approach a single filter element may be employed over each photosensor array,

5 whereas in the case where photosensors of a given color channel are spatially distributed with those of other channels in a single array, a mosaic of filters will be employed over the array. However in each case at least one color channel is divided into sub-channels including

10 at least one sub-channel tuned to record a broad band of wavelengths and one tuned to record a narrow band of wavelengths. In the example given above the green channel is divided into two sub-channels using respectively a Kodak^{tm} Wratten^{tm} #58 (green tricolor) filter to select a

15 broad band of green wavelengths and a Kodak^{tm} Wratten^{tm} #99 (green) to select a narrow band of green wavelengths. On the other hand the Red and Blue channels may use respectively a Kodak^{tm} Wratten^{tm} #25 (red tricolor) to select a broad band of red wavelengths and a Kodak^{tm}

20 Wratten^{tm} #47 (blue tricolor) to select a broad band of blue wavelengths.

The intensity of light falling on each photosensor is measured using one or more sensor arrays of a type such as

25 the Sony ICX205AL and digitized using a suitable analog to digital converter. For the green channel, and/or any other channel that has multiple sub-channels, the sub-channel signals are scaled and extended 610 by interpolation of signals from the other sub-channels of

30 the same color channel. Therefore, in the case of those areas of input intensity where one of the sub-channel sensors is producing an output that is either at the black level or the saturation level, the suitably scaled outputs of other photosensors of the same color channel are used

35 to interpolate a signal for the photosensor that has an output at the black level or the saturation level.

Finally the color channel and sub channel signals are color corrected 612 using, for example, 4 x 3 color correction matrix, to produce a digital image with three
5 channels of color such as an Srgb image. The color correction step is also known as demosaicing, and is used to convert the raw image data from the photosensor array into a resultant standard image format; that is, calculating the red, green, and blue intensities of
10 nominal pixel locations of the resultant image from the photosensor array data. Since respective color channels of the photosensor array may not be aligned to a rectangular sampling geometry, an algorithm such as that proposed by David Taubman may be utilized (Taubman, David.
15 Generalized wiener reconstruction of images from color sensor data using a scale invariant prior, Proceedings of the 2000 International Conference on Image Processing (ICIP 2000), 10-13 September 2000). A variation of this algorithm may be employed to allow for the multiple sub-
20 channels within a single color channel.

Thus various embodiments and components have been shown for creating an image sensing system, and these may be used singly or in combination, or with other elements
25 known in the arts of optical design, and color science. It is understood that these and other such combinations, substitutions, and alternative embodiments may be undertaken according to the requirements and materials at hand without deviating from the spirit of the invention,
30 the scope of which is to be limited only by the claims appended hereto.